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Determination of essential parameters influencing service life time of polyurethane insulation in district heating pipes

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Abstract

Pre-insulated district heating pipes (DHP) have been in use during the last forty years. Many improvements and development have been done in the system. However, life-time prediction is still an uncertain issue. This paper is a part of a bigger project with the objective to determine mechanisms related to the deterioration of the mechanical and insulation properties of pre-insulated heating pipes as a result of ageing. The focus in this project is on degradation mechanisms of the PUR material at high temperatures. In this paper some results of the two types of exposure are presented. The first type comprises a condition where the new pipes are subjected to accelerated ageing at three different temperatures. The second type comprises condition, when the PUR material itself is aged in different atmospheres in order to identify different degradation mechanisms. The chosen ageing temperatures in the first condition were 130°C, (close to the supply temperature), 150°C and 170°C, (accelerated ageing temperature in EN 253 [1]). Changes in thermal insulation and the adhesion force between the PUR and the steel pipe were evaluated using the transient plane source (TPS) technique and the SP plug method respectively. The results of ageing show that the degradation of PUR is a multi-stage process composed of a rapid change in properties followed by a plateau phase which changes later to a gradual deterioration of the properties. The results of the PUR material exposure at 150°C in air and in nitrogen showed significant differences in the degradation characteristics between the two environments as were revealed by DSC and FTIR methods.

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Keywords: Polyurethane insulation; District heating pipe; PUR degradation; Accelerated ageing; Life time prediction

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1. Introduction

Thermal energy makes up about 50 % of the worldwide energy use and all over the world goals are made to reach lower and lower energy consumption. For example under the EU Energy Performance of Buildings Directive (2002/91/EC, EPBD), EU member states are required to achieve near zero energy status for all new constructions by 2020. All these goals demand development of more sustainable district heating systems (DHS).

Pre-insulated district heating pipes (DHP) have been in use during the last forty years in different countries. A pre-insulated pipe contains a steel pipe as media pipe, polyurethane (PUR) foam as insulation and a high density polyethylene (HDPE) pipe as mantel. Until now, many improvements in manufacturing methods have been introduced and some developments of the pipe component materials have been performed [2], [3]. The most important was the phase-out of the chlorofluorocarbons (CFC) in the 1990s and the use of high-density polyethylene for the casing pipe in order to improve the pipe's long-term property. Changing uni-modal HDPE to bi-modal and foam gas from CFC to cyclopentane has improved some functionality and technical performance, however, life time prediction is still an uncertain issue. Improvement of thermal insulation and mechanical properties of the PUR foam has a great relevance to minimize energy losses from the DHPs. The importance of studying thermal degradation, understanding the processes occurring during thermal stress as well as the parameters affecting the thermal stability of PUR insulating material are essential in order to effectively design the pipe and in particular polyurethanes properties suitable for a certain environment. Furthermore, the foam is expected to restrain axial movement due to thermal changes of the pipeline. Most of the studies related to the parameters that can have impact on ageing are focused on the analyses of gas diffusion through PE jacket or diffusion process and associated change in the cell gas composition in the PUR insulation [4], [5]. These works have focused on the relation of the diffusion of oxygen and replacement of the cell gases to the decrease of the foam strength.

As district heating networks operate with high service temperatures up to 120 °C, a good long-term heat resistance is necessary to maintain the most important properties e.g. good adhesion of the foam to the pipe and good insulation efficiency. The minimum properties the foam must fulfil are outlined in the European quality norm for pre-insulated bonded pipe systems for buried hot water networks, EN 253. This standard, prescribes the life time prediction of pipes by testing and evaluation of the adhesion strength between PUR and steel pipe after accelerated ageing at an elevated temperature of 170 °C. The expected life time for PUR insulation is calculated using Arrhenius relationship.

To understand how the thermal and mechanical properties of PUR foam are related to each other and how they are changed with time at high service temperatures further studies are needed.

This paper reflects a part of a Ph.D. research project. The main aim is to study and determine the different degradation mechanisms in PUR foam over time. Furthermore, another objective is to improve the model used to calculate the expected service life of a DHP.

2. Experimental

Results from the previous projects have shown that a better understanding of the degradation mechanisms of PUR when it is aged at high temperatures is needed [5]. In this project, three DHP DN50/160 of length 4 m with a 3 mm thick PE casing were placed in a chamber with a controlled ambient temperature. The DHPs were manufactured by Power Pipe in Gothenburg using the traditional discontinuous, pour-in-place method filling the pipe from one of the pipe ends, which gives some variations in the overall density of the PUR.

The chosen ageing temperatures were 130 °C, which is very close to the highest working temperature of DHS, 150 °C and 170 °C, which is used as accelerated ageing temperature in EN 253. The steel pipes of the DHP were connected to a controlled electric source. Before blowing of the polyurethane mantel, some temperature sensors were placed in the DHP to follow the internal temperature at the contact surface between the PUR and the steel serve pipe during the experiments. These sensors were placed along the steel service pipe; one of the sensors was placed in the middle of the DHP and the other two sensors in the ends.

In the same way, two special thermal sensors made by Hot Disc AB were placed in the PUR insulation of the DHP at two distances from the steel pipe viz. 5 mm and 30 mm. The sensors are both heat source and temperature sensor, which means, they are able to measure the thermal transport property and the real temperature in the PUR

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